GEOCHEMICAL EVIDENCES FOR TWO CHONDRITIC-LIKE COMETARY OR ASTEROIDAL IMPACTS BEFORE AND AT THE K/T BOUNDARY; **Y.-G. Liu[1,2] and R.A. Schmitt[1-4], [1]The Radiation Center and Departments of [2]Chemistry and [3]Geosciences, and [4]College of Oceanography, Oregon State University, Corvallis, Oregon 97331**

Mass extinctions caused by multiple impacts of cometary showers within a short time period have been proposed by [1-3]. Detailed calculation of temporal profile shows that cometary showers last ~3 Ma, with the bulk of the comets arriving within ~1 Ma. A number of geological and palaeontological evidences support multiple impacts and their connection with mass extinctions. Observations [2] include clustered crater ages, stratigraphic horizons of impact ejecta closely spaced in time, and evidence for stepwise mass extinctions spanning intervals of 1-3 Ma. For the K/T boundary, three candidates, Popigai, Manson, and Yucatan, have been proposed as impact craters [3]. Two distinct strata at the K/T boundary in western North America have been interpreted [4,5] as evidence for two sequential impacts. If multiple impacts occurred within a time span of ~1 Ma then multiple Ir enrichments should be observed.

DSDP Hole 577B on the Shatsky Plateau (Rise) in the northern Pacific at ~12°N at K/T time is the first site. At this site, the K/T boundary was undisturbed and well recovered. Samples contain $\gtrsim$97% $CaCO_3$, which exhibit clear chemical signals associated with asteroidal/cometary impact. Ir, Fe, and Cr data from Hole 577B [6] are plotted in Fig. 1. All data are normalized to Th. In the study of this site [9], we found that the normalized abundances of Al, Hf, Ta, and Th essentially overlap the N.A.S.C. (North American Shale Composite) abundances; i.e. the detrital component in these carbonate sediments resemble the N.A.S.C. composition. Considering the very low Th concentration in seawater, ~3±2 x 10^{-5} μg/L [10], little Th is precipitated from seawater onto the detrital clay; therefore, Th is an excellent diagnostic aeolian clay indicator. From the Th-normalized Ir data, two satellite peaks below the major peak at 78 cm and 81 cm of 577B-1-4 are clearly shown. The major Ir peak (K/T boundary) is at 72 cm. Fe and Cr, from C1-like impactor ejecta fallout [11], also show two peaks at the same positions.

Hole 738C on the southern Kerguelen Plateau has been studied by [7]. A complete K/T boundary sequence was recovered. The Ir values reach a peak concentration of 18 ppb in the clay layer at 96.0-96.2 cm in section 20R-5, and gradually tail off. But in the sample 115 cm above the boundary, Ir concentrations have still not reached background levels. From the Ir peak downward to the lowermost sample analyzed at 102 cm, the Ir concentration is still as high as 1.7 ppb. From the Th-normalized data in Fig. 2, we observed a small Ir/Th peak at 100-101 cm. Though this peak is within the error margin, the trend is clear. Fe and Cr exhibit the same pattern.

The third case is Hole 690C on the Queen Maud Ridge. Trace element studies have been reported by [8]. Applying the same Th normalization procedure to Hole 690C data, we obtained Fig. 3 for Ir and Fe. Cr was not measured at all levels like Ir and Fe by [8], and also the large Cr errors precluded estimates of the Cr/Th pattern. Again, the Ir/Th plot indicates the strong possibility of satellite peaks at ~52 cm. The main peak is at 39-40 cm. It was noted that the Hole 690C K/T boundary was bioturbated [12]. Due to the high clay content, one would expect that only ~2% of the observed total Fe in the Ir peaking samples would be from impactor ejecta fallout. Therefore, use of Fe/Th ratios will not permit accurate estimates of Fe_{net} and also not permit us to define precise Fe/Th satellite peaks.

It seems significant that the background level of Ir/Th at 690C-15X is obtained for samples that contain ~54% detritus (0-21 cm) and ~15% detritus (100-145 cm), which indicates a uniform Ir of ~0.20 ppb in the detrital NASC-like clay component. For example, the background level of Ir in the 15X-5-0-29 interval is equivalent to ~0.24 ppb Ir in NASC-like detrital clay, assuming all Ir is in the clay component. Similarly, for eight background samples before the K/T boundary in the 15X-4-90-145 interval, a value of 0.16 ppb Ir in NASC-like detrital clay is obtained. These levels of Ir are consistent with 0.5±0.3 ppb Ir in 24 pelagic clays [13] and 0.39 ppb Ir in 34 Gubbio "background" shales [14].

Observations by [15,16] indicate that the stratification of trace elements appears threefold with peak concentrations in sublayers A1, A3 and B2 for different element groups, including Ir, in the Stevns Klint K/T boundary layers. C1 ratios for many siderophile elements were found by [17] in combined layers III and IV, corresponding to layers A, B, C and D. These C1 ratios for combined layer samples strongly support the impact hypothesis and also an indication of redistribution between layers. Recent data [15] do not indicate a satellite peak before the main K/T peak at the Stevns Klint. The clay rich K/T boundary plus the bioturbation and excessive organic carbon preclude any attempt to find such evidence.

Multiple Ir anomalies in the K/T section at Lattengebirge, Bavarian Alps are reported [18]. The main peak of 4.4 ppb is precisely at the boundary. A peak of 3.6 ppb was detected at 16 cm below the boundary, corresponding to 14,000-9,000a before KTB. The third peak of 2.8 ppb is 10 cm above the KTB. They suggested an alternative causative agent for the K/T events like prolonged and intense volcanism combined with sea-level and climate changes. But the recent works on Ni-rich spinels and Ir at the K/T boundaries [19,20] clearly establish cometary/asteroidal impactors at the K/T boundary. The pre K/T Ir enriched layer could be ascribed to a cometary impact. The third peak ~10 cm above the KTB has an Ir enrichment of ~6X relative to average pelagic clays. In Hole 577B 0.073±0.009 ppb Ir in carbonate rich sediments ~3 m (~1 Ma) above the K/T boundary was reported [6]. This is equivalent to 1.8 ppb of Ir in the NASC-like detrital clay in the sample. We cannot rule out another cometary impact after the main K/T event.

The Ir contents in Gubbio shales ~2m above and below the K/T boundary (i.e. over ~1 Ma interval and K/T boundary shale values were excluded) were ~5X higher relative to Ir contents in shales 6-219 m below the K/T boundary [14]. Observations by [21] indicate similar Ir enrichments above background over 1-2 m of section with a peaking at the K/T boundary at the Stevns Klint, Carravaca, and Bidart, France, with an estimated enhancement duration of ~10^4a. Volcanism was favored by [14]; however, the cometary showers [2] explains the enhanced Ir contents over ~1 Ma as well.

In conclusion, the data from three world wide sites such as Shatsky Rise (Holes 577, 577B), Kerguelen Plateau (Hole 738C) and Qeen Maud Ridge (Hole 690C), where K/T sediments were deposited in different chemical regimes from intermediate depth at the K.P. Hole 738C of ≤300m to deep oceanic sites (1800-2400 m) for the S.R. and Q.M.R. sites, strongly indicate a small satellite Ir/Th peak before the main Ir/Th peak at the respective K/T boundaries. From estimates of the sedimentation rates at the three sites, the time intervals between the satellite and the main Ir/Th peaks are ~8000a (S.R.), ~2000a (K.P.), and 13,000a (Q.M.R.), with a most probable value of ~6000a.

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